ECLIPS
Enhancing Concrete Life in Infrastructure through Phase Change Systems

Infravation
An Infrastructure Innovation Programme

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Use of phase change materials (PCMs) to mitigate early age thermal cracking in concrete: Theoretical considerations

Use of microencapsulated PCMs in thermal crack mitigation

During construction, temperature in concrete will increase due to exothermic hydration reactions of cement. As the surface of the structure will lose heat to the atmosphere, and a thermal gradient will appear between the cold outside and the warm core of the structure or element. Internal or external restraints, which can stop hardening concrete from expanding and contracting freely, may give rise to occurrence of tensile stresses and, consequently, cracking. This is a common problem in engineering practice. The use of microencapsulated phase change materials (PCMs) as additives can help with temperature rises in mass concrete. A phase change material has high heat of fusion which can, by melting and solidifying at a certain temperature, store and dissipate large amounts of energy in the form of heat. In designing cementitious materials with PCM addition for crack control, numerical modelling can be of great help. A cement paste/PCM microcapsule composite is simulated as shown in Figure 1.

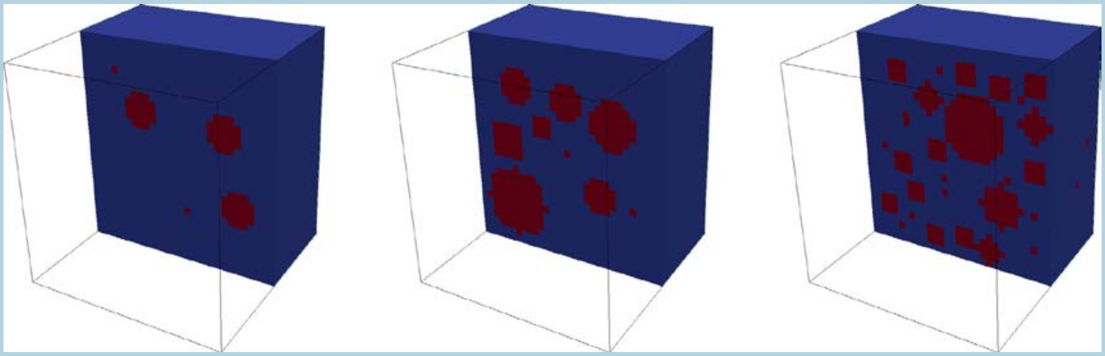

Figure 1: Cementitious material structures comprising PCM microcapsules (cut in the middle to show PCM microcapsules) and cement paste with (PCM left to right) 10%, 20%, 30% microcapsules (shown in red) per volume. Blue represents the cement paste matrix

Material scale

At the level of the material, the influence of PCM microcapsule addition and their thermal properties on hydration temperature rise in cement paste can be considered. In order to mimic the experiments, a part of the cement paste was replaced by PCM microcapsules. For simplicity, the microcapsules are considered to comprise only PCM, without a hard shell. The phase change capsules have a twofold effect on the internal heat generation in the composite: first, they have a diluting effect due to the fact that they replace a part of the hydrating cement; and second, the phase change effect. An example of a simulation considering adiabatic temperature rise for PCM composite paste (with a phase change temperature of 25°C). Clearly, PCM microcapsule addition has the potential to delay the temperature rise in adiabatic conditions. But, what about real site conditions?

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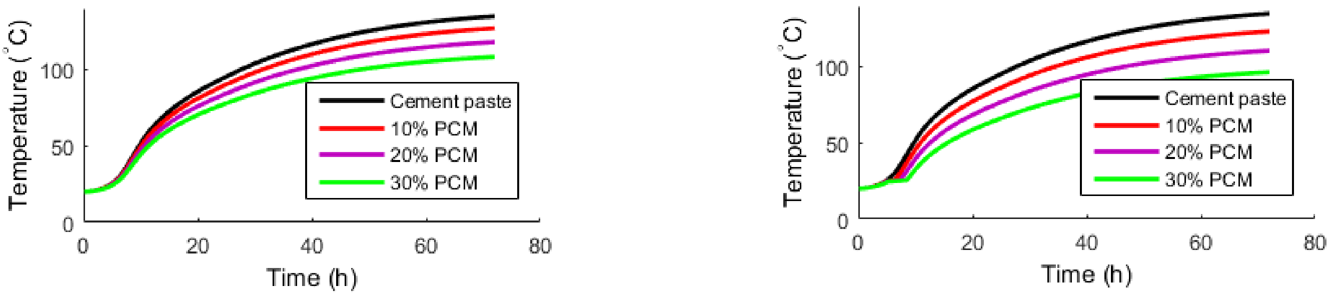
Figure 2 (below): Simulated adiabatic temperature evolution in a cement paste containing different amounts of PCM microcapsules and without (left) and with (right) considering their latent heat contribution.



Structural scale

On the structural scale, the influence of PCM additions on the risk of early-age cracking is assessed on the macro (i.e. structural) scale. Commercial finite element package FEMMASSE is used to simulate temperature evolution and stress distribution at this scale. As an example, a massive wall-slab system shown in Figure 3 (below) is analysed. It is assumed in the analysis that the base slab has already hardened, and is restraining the thermal deformation occurring in the hardening wall. This is a typical scenario which could potentially lead to through cracking in the concrete wall. It is assumed further that the initial temperature of the base slab is 15 °C, while the initial temperature of the young concrete is 20 °C The structure is exposed to the constant environmental temperature of 15 °C.

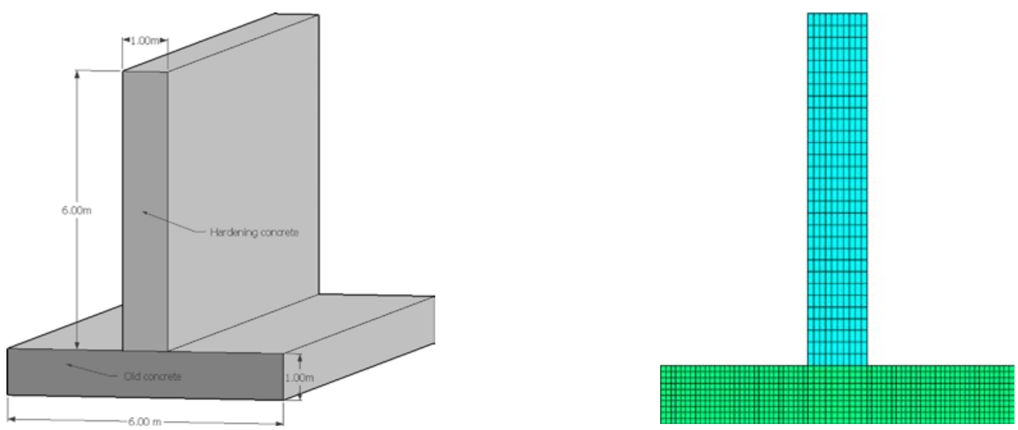


Figure 3: Geometry of the wall-slab system analysed (left) and the FE mesh used (right).

Different amounts of PCM microcapsule additions can be used, and the results in terms of maximum temperature and maximum out-of-plane tensile stress are given in Figure 4 (below). It is clear that higher PCM amounts may decrease the maximum stress significantly. This study provides a theoretical basis for design and development of concretes with microencapsulated PCM additions for thermal crack control. Future work will include experiments and large scale testing of the material.

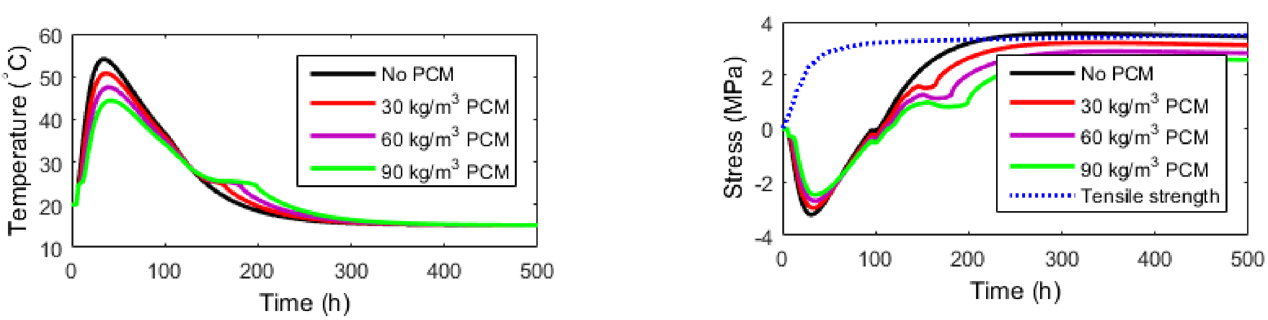


Figure 4: Simulated development of maximum temperature (left) and out-of-plane tensile stress (right) in a hardening concrete

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